Pertanika J. Soc. Sci. & Hum. 27 (S3): 81 - 97 (2019)

SOCIAL SCIENCES & HUMANITIES

Journal homepage: http://www.pertanika.upm.edu.my/

Effects of Barefoot and Shod Running Training on Running Performances among Recreational Runners

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ABSTRACT

The running phenomenom has gained popularity over the past decades in Malaysia. However, running with shod or barefoot is still a debatable topic among runners and researchers. As such, this study investigated the effects of running with shod or barefoot on the predicted $VO_{2\ max}$ and ground reaction force (GRF). Twenty subjects (7 males and 3 females in each of the group) with no barefoot experience (EG, AGE: 20.1 ± 2.1 years, Running Experience: 2.6 ± 1.2 years and CG, AGE: 20.7 ± 1.7 years, Running Experience: 3.0 ± 1.3 years running experience) participated in this study. Predicted $VO_{2\ max}$ was calculated from 2.4 km run test while GRF for left leg (LL) and right leg (RL) were obtained from force plate analyses. Subjects were divided into 2 groups which were experimental (EG-barefoot) and control (CG-shod) groups based on the pre-test results. Both groups completed 6-weeks of intervention programme with twice a week of running training adapted from Mullen et al. (2014) at outdoor running track. The study found significant improvement in VO_2 of EG as compared to insignificant improvement in CG and revealed a greater reduction in the GRF for BF compared to shod runners. Results showed that EG improved significantly in the $VO_{2\ max}$ during post-test as in compared to pre-test (42.9 ± 7.5 vs. 40.7 ± 7.4 $ml.kg^{-1}min^{-1}$; p=0.09). However, no significant difference was found in GRF between pre and post-tests in EG (LL: 1380.3 ± 271.8 N vs. 1340.4 ± 177.0 N, p = 0.59 & RL: 1389.1

ARTICLE INFO

Article history:
Received: 6 May 2019
Accepted: 31 October 2019
Published: 30 December 2019

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ISSN: 0128-7702
e-ISSN: 2231-8534

± 313.2N vs. 1326.3 ± 218.7 N, $p = 0.43$). In CG, no significant changes were found in VO_{2max} and GRF ($p>0.05$) between pre-and post-tests. Even though the results of GRF did not show significant improvement in both groups, ~ 3.5% of slight decrement in GRF was found in EG. We speculate GRF can be reduced further with the increase of training volume. Thus, barefoot running training can be a tool to improve running performance in recreational runners.

Keywords: Barefoot running, foot strike pattern, ground reaction force, running performance

INTRODUCTION

Running has become more popular over the past decades in Malaysia. Running is considered as the most important recreational activity (De Wit et al., 2000) and is one of the most popular and widely practiced sports worldwide (Statista, 2018). Running's increased popularity worldwide is due to its high accessibility and low cost (Sun et al., 2018). In the USA alone, the popularity was reflected in almost 60 million people jogging in 2017 (Statista, 2018). Similarly, the healthy recreational running industry was reported to be thriving in the U.S as nearly 18.3 million people participated in the road races in 2017 ("U.S. Road Race", 2018). While many people enjoy running as a recreational activity or to maintain their fitness level, some others participate in competitive running. Running provides numerous physiological and psychological health benefits. The benefits include improved cardiovascular health (Williams, 2009a), decreased risk of stroke (Williams, 2009b) and hypertension (Mota et al., 2009), increased bone mass (Drysdale et al., 2007; Wilks et al., 2009) and psychological benefits such as decreased depression and a positive effect on mood state (Doyne et al., 1987; Schneider et al., 2009).

Running statistics are said to be influenced by footwear manufacturers in recent times. Running enthusiasts were attracted toward shoes that offer comfort, superior shock absorbent cushioning, motion control or stability, which provide a smooth and efficient running motion. This inclination is supported by the billions of dollars in revenue for the shoe industry in 2018 with Nike leading the pack with 22.27 billion (11.52 billion in 2010), Adidas achieved 12.78 billion (7.14 billion in 2010) and Puma reaped 2.5 billion (1.89 billion in 2010) (Statista, 2018). Even though continuous research and advanced technology had produced numerous types of good performance running shoes, the overall running injury rates have not been reduced. In a 2017 research, Running USA surveyed about 6,800 runners and reported that 75% of the respondents had had a running-related injury in the past 12 months, 50% had had their training curtailed for more than 4 days due to the injury. In fact, earlier research data had reported a prevalence of running-related injuries to range between 50% and 79% per year (Altman & Davis, 2012; Buist et al., 2010; Ferber et al., 2009; Fields et al., 2010; Kaplan, 2015; Taunton et al., 2002; Van Gent et al., 2007).

The persistent high rate of running injury despite advanced shoe technology (Davis, 2014; Rixe et al., 2012) has prompted Americans search for other ways to experience the benefits of running. Thus, barefoot (BF) running form has been suggested as a potential mechanism to reduce running injuries (Lieberman, 2012). Previously, McNair and Marshall (1994) suggested that BF was associated with kinetic and kinematic changes which resulted in decreased stride length and a more plantarflexed position at ground contact, that consequently helped prevent injury. Similarly, in examining the impact acceleration of BF and shod running, Thompson et al. (2016) revealed that there were significant differences in impact peak magnitude between BF and shod runners. In addition, in an online survey of 509 runners with some BF running experience conducted by Hryvniak et al. (2014), it was reported that 64% of them experienced no new injuries after starting BF running and 69% of them was free of previous injuries after starting BF running. This was echoed by Tam et al. (2014) that claimed BF running had become a popular research topic and gained significant attention due to its alleged benefits for runners of all levels. These benefits include the potential for reduced injury risk, and more economical running. In reviewing 96 relevant articles on the benefits of BF running, Kaplan (2015) reported differences in gait and other parameters between BF and shoe running and concluded that barefoot runners had fewer injuries, and better running performance. Similar findings were also revealed in the earlier review by Jenkins and Cauthon (2011) which stated that BF runners had fewer injuries and had better performance.

In terms of running economy (RE), BF runners who often are forefoot lander (Larson et al., 2011; Lieberman et al., 2015) as compared to about 90% shod runners who typically experience rear foot landing (Hasegawa et al., 2007; Lieberman et al., 2010; Onwaree, 2014), have better RE. Heel striking shod runners create braking forces which would generate more resultant vertical force instead of horizontal force during each running stride while running (Gisela et al., 2016; Mullen et al., 2014; Perkins et al., 2014; Tam et al., 2016). Consequently, the braking forces would increase the demands of energy expenditure and also reduce the speed of moving forward that induce poor RE (Marc, 2003). Conversely, BF running promotes forefoot landing that reduce the braking forces with the slight forward lean of the body which could convert the reaction force bounce forward rather than vertical direction. Without the braking force, running economy could be improved by 1 to 3% with forefoot landing pattern (Owen, 2013).

Similarly, Hanson et al. (2011) when investigating the oxygen cost of running BF versus running shod on the treadmill as well as over ground on 10 healthy recreational runners, reported that VO_2 while running shod was 5.7% and 2.0% higher than running BF on over ground and treadmill respectively. The huge over ground VO_2 increase might be explained using the Divert et al. (2008) rationale that there was a rise in elastic energy storage during barefoot running when running over ground as compared to running on the treadmill. In a meta-analysis conducted by Cheung and Ngai (2016) in 13 studies and on 168 runners, it was found that BF running was shown to be more economical than shod running, requiring less oxygen consumption when running. BF running claims to have the ability to enhance proprioception feedback which is able to perfect landing mechanism for lower limbs injury prevention and also enhance running economy that is linked to the natural efficient landing stride (Perkins et al., 2014). Furthermore, other researchers (Jason & Rodger, 2012; Hanson et al., 2011, Tam et al., 2016) also concurred that BF running is much more economical than running shod as BF running eliminated the additional weight of the running shoe and numerous uncomfortable feelings that restricted the movement of both feet. In addition, Tung et al. (2014) reported that shoe added weight on runners which consequently increased the rate of oxygen uptake, energy expenditure and the heart rate response and thus impairing running economy.

Even though different strike patterns (Fore Foot Strike [FFS] versus Rear Foot Strike [RFS]) have led to numerous hypotheses about their relative costs and benefits, many researchers found no difference in terms of RE between FFS and RFS (Cunningham et al., 2010; Gruber et al., 2013; Perl et al., 2012). Similarly, Shih et al. (2013) reported that being shod or BF made little difference to RE rather, a forefoot strike would improve RE in comparison to a heel-strike. FFS and some MFS landings differ from RFS landings in generating no observable impact peak in the vertical Ground Reaction Force (GRF) just after contact (Hreljac et al., 2000; Milner et al., 2006; Pohl et al., 2009). Similarly, the extensive experimental tests conducted by Lieberman et al. (2010) found that forefoot strike generates substantially lower impact forces than those observed for RFS. FFS runners experience no impact peak and lower loading rates of the GRF compared to RFS runners (Hamill et al., 2011; Lieberman, 2012; Lieberman et al., 2010; Squadrone & Gallozzi, 2009). Over the last decade, Cheung and Ngai (2016) observed that BF running or running in minimalist shoes was getting popular not only as a way to minimize the risk of overuse injuries, but also as a potential strategy to improve RE.

The benefits of shod running and BF running are still inconclusive with both sides of the divide claiming their methods are better in improving running economy and reducing foot injury. Despite the heavy debate, there was a lack of research in Malaysia about the effects of BF training on RE. Thus, the purpose of this study was to compare 6-week shod running and barefoot running effects on RE and GRF.

METHODS

Participants

Twenty subjects (14 males and 6 females) with no barefoot experience (EG: 20.1 ± 2.1 yrs, 2.6 ± 1.2 years running experience and CG: 20.7 ± 1.7 yrs; 3.0± 1.3 years running experience) participated in this study. This study was carried out at the Tunku Abdul Rahman University College Kuala Lumpur (TAR UC KL). Referencing Wilmore and Costill (2005), this study targeted a sample of recreational runners with average VO_2 max values of 44.9 ± 6.90 ml/kg/min for male and 34.2 ± 3.84 ml/kg/min for female, or able to complete 2.4 km run with the average timing of 12 ± 2 min for male and 16 ± 2 min for female.

Design of the Study

The design of the study involved pre-test, intervention, and post-test. The participants were divided into 2 groups (EG, n=10; CG, n=10). The CG performed the running training programme wearing modern running shoes of their choice and the EG performed the running training programme barefooted. Both groups underwent a similar intervention programme for 6 weeks. Pre-test and post-test were conducted before and after the 6 weeks intervention duration. Both groups were tested using a 2.4 km run test and force-plate analysis for the pre-test and post-test. After pre-test, the subjects were ranked according to the total z-score based on the 2.4 km run test and force-plate analysis. Then, subjects were assigned into 2 groups using a systematic counter balancing method. The EG and CG were randomly determined using fishbowl method.

Training Programme

This 6-weeks running training programme (Table 1) was adapted from Tam et al. (2016). The programme applied the principle of progressive overload. EG and CG applied the same 6-week training programme. The EG ran barefooted and the CG ran with running shoes. The intervention programme was conducted 2 times per week. The subjects were not briefed in terms of foot strike pattern and were instructed to run in the way that was most comfortable to them.

Table 1

Six-week barefoot running training program for Control Group and Experimental Group

Group/Test	N	Mean ± SD	Df	t-value	Sig.
Pre-test					
EG	10	40.72 ± 7.41	18	0.384	0.493
CG	10	42.06 ± 8.12			
Post-test					
EG	10	42.85 ± 7.49	18	0.384	0.816
CG	10	44.05 ± 7.91			

*The mean difference is significant at the 0.05 level

Procedure

The Physical Activity Readiness Questionnaire (PAR-Q) form was prepared for all the subjects. Subjects filled-up the PAR-Q form and returned them to the researcher. Only subjects without any medical conditions were accepted for the study. Once accepted, the subjects were given a background information form to fill up. Background data such as age, body weight, height, leg length, running experience and 10 km best time were collected. Consent forms were distributed to all the subjects. Prior to signing the form, a briefing was provided regarding the research procedure, possible benefits and hazards during training, and confidentiality of the collected data. The consent form was signed and returned to researcher after the briefing session.

Before the pre-test, subjects underwent a short briefing on the test protocol to ensure that all subjects were familiar with the tests. Subjects performed a standardized warm-up (Jumping Jack, 10 repetitions; Forward Lunge, 10 repetitions; and Mountain Climbers, 10 repetitions) before running on the track. Subsequently, subjects ran on the force-plate with self-selected pace to determine the ground contact force for both legs separately.

2.4km Run Test (Burger, 1990; r = 0.92, pilot study = 0.86)

The test was performed on the measured 2-lane running track and were required to run for 2.4 km. Subjects started to run on the signal 'GO', and ran 2.4 km with their best efforts. The total time of completion was recorded by the researcher and it was used to calculate the predicted VO_2 max value. Estimation of the VO_2 max for 2.4 km formula was determined using the formula below.

$$VO2\,max\left(ml.\frac{kg}{min}\right) = 3.5 + [483/2.4km\ time(min)]$$

Force-plate Analysis (Sebastian, 2015; r = 0.96)

Subjects were asked to run with modern running shoe (CG) or barefooted (EG) with self-selected running pace on the force-plate (Bertec Force Plate - Columbus) embedded in the laboratory floor. The force-plate was used to measure the GRF. The GRF was recorded after the subjects ran through the force-plate. The subjects performed force-plate run 3 times for each leg (right and left) and the mean scores were used for further statistical analyses.

Data Analysis

Statistical analyses were performed using Statistics Package for Social Science (SPSS) Ver. 19. Means, standard deviations, minimums and maximums were calculated for predicted VO_2 max and GRF. The demographic data of the subjects such as gender, age and years of running experience were also reported. T-tests were used for comparative analyses. The level of significance was set at $p < 0.05$.

RESULTS

Comparing the Predicted VO_2 Max in the Pre-test and Post-test between CG and EG

The Independent T-test result in Table 2 showed that the pre-test t-value of 0.384 was not significant (p=0.493) at 0.05 significant level. This showed that EG and CG started equal in terms of VO_2 max.

Similarly, the post-test comparison between CG and EG also revealed a non-significant result. The results did not support the notion that BF running was better than shod running in improving VO_2 max.

Results in Table 3 and 4 indicated that the EG had increased significantly in the predicted VO_2 max by 5.23 % (from 40.72 to 42.85 ml/kg/min) when comparing pre-test and post-test results. Similarly, the CG has also increased their predicted VO_2 max by 4.73 % (from 42.06 to 44.05 ml/kg/min).

Comparing the GRF (Ground Contact Force)(measured by FPA) in the pre-test between CG and EG

Data analyses in Table 5 and 6 showed insignificant results in both the pre-test and post-test ground contact force mean values between CG and EG. These results revealed that both groups were similar before intervention and had no superiority over each other after the intervention duration.

Table 2

A comparison on the running economy (predicted VO_2 max value by 2.4 km run) in the pre-test and post-test between CG and EG

Group	N	Test	Mean ± SD	df	t-value	Sig.
EG	10	Pre	40.72± 7.41	9	-3.288*	0.009
		Post	42.85 ± 7.49			
CG	10	Pre	42.06 ± 8.12	9	-1.722	0.119
		Post	44.05 ± 7.91			

*The mean difference is significant at the 0.05 level

Table 3

A comparison of the pre and post-test (predicted VO_2 max measured by 2.4km run) for CG and EG

Group	Test	Mean	S.D.	Median	Min	Max	Percentage
EG (n=10)	VO_2max Pre	40.72	7.41	19.62	31.42	51.04	5.23
	VO_2max Post	42.85	7.49	21.39	32.74	54.13	
CG (n=10)	VO_2max Pre	42.06	8.12	19.60	31.63	51.23	4.73
	VO_2max Post	44.05	7.91	21.07	32.79	53.86	

*The mean difference is significant at the 0.05 level.

Table 4

A comparison of improvement of predicted VO_2 max (2.4 km run test) for EG and CG

Side	Group	N	Mean ± SD	df	t-value	Sig.
Pre-test						
LL	EG	10	1380.36 ± 271.79	18	0.989	0.884
	CG	10	1503.17 ± 283.31			
RL	EG	10	1389.12 ± 313.21	18	0.825	0.593
	CG	10	1499.80 ± 286.25			
Post-test						
LL	EG	10	1340.397 ± 177.046	18	1.324	0.127
	CG	10	1477.964 ± 276.700			
RL	EG	10	1326.305 ± 218.665	18	1.522	0.258
	CG	10	1491.647 ± 265.086			

*The mean difference is significant at the 0.05 level; Note: LL = left leg, RL = right leg

The pre-post mean scores comparison in Table 5 has showed insignificant differences in the mean LL and RL scores for each EG and CG.

Table 5

A comparison on the running economy (ground contact force measured by FPA) in the pre-test and post-test between CG and EG

Side	Group	N	Test	Mean ± SD	df	t-value	Sig.
LL	EG	10	Pre	1380.361± 271.790	9	0.558	0.590
			Post	1340.397 ± 177.046			
	CG	10	Pre	1503.169 ± 283.311	9	0.521	0.615
			Post	1477.964 ± 276.700			
RL	EG	10	Pre	1389.115 ± 313.208	9	0.820	0.433
			Post	1326.305 ± 218.665			
	CG	10	Pre	1499.797 ± 286.253	9	0.148	0.886
			Post	1491.647 ± 265.086			

*The mean difference is significant at the 0.05 level; Note: LL = left leg, RL = right leg

However, the force-plate analysis results in Table 6 showed that the left LL GRF for EG reduced by 2.9 % (from 1380.36 N to1340.40 N) while the RL also indicated a reduction of 4.52 % (from 1389.12 N to 1326.31 N). As for CG, the LL ground contact force indicated a decrease of 1.68 % (from 1503.17 N to 1477.96 N) while the RL a 0.54 % reduction (from 1499.80 N to 1491.65 N).

Table 6
A comparison of the pre and post-test (ground contact force for LL & RL measured by FPA) for CG and EG.

Group	Test	Mean	S.D.	Median	Min	Max	(%)
EG (n=10)	FPA Pre (LL)	1380.361	271.790	777.158	1028.283	1805.441	-2.9
	FPA Post(LL)	1340.397	177.046	561.475	1078.227	1639.702	
	FPA Pre (RL)	1389.115	313.208	822.347	1030.213	1852.560	-4.52
	FPA Post (RL)	1326.305	218.665	747.054	1062.489	1809.543	
CG (n=10)	FPA Pre (LL)	1503.169	283.311	809.27	1098.444	1907.714	-1.68
	FPA Post (LL)	1477.964	276.700	844.140	1103.294	1947.434	
	FPA Pre (RL)	1499.797	286.253	853.599	1031.862	1885.461	-0.54
	FPA Post (RL)	1491.647	265.086	707.343	1179.125	1886.468	

*The mean difference is significant at the 0.05 level; Note: LL = left leg, RL = right leg

DISCUSSION

This study compared the effects of BF and shod running on running economy in recreational runners. The experimental study was conducted on 20 recreational runners from TARUC KL.

Barefoot and Shod Running and Predicted VO_2 Max

This study revealed non-significant post-test results of the Predicted VO_2 max (p=0.816). This result supported Kalina et al. (2016) insignificant difference in Running Economy (RE)(BF 31.5 ± 2.65 vs RS 30.21 ± 2.91; p = 0.086) when studying 9 female athletes (age 21.1 ± 1.79 years old) with no previous BF running experience. Similarly, in another study of 15 male runners (age 27.8 ± 5.1 years old) with no BF running experience using 8-week progressive BF running training programme, Tam et al. (2015) found that oxygen cost of transport was not significantly different between runners running BF and those running with shod.

In a study of 21 experienced runners comparing the oxygen cost and other variables between BF and shod running, Vincent et al. (2014) found no significant difference in the steady state VO_2 between the shod and barefoot conditions (39.4± 4.7 ml/kg/min vs. 40±5.2 ml/kg/min, respectively). The total energy expended in the shod and BF conditions was 974±134 kJ and 979±142 kJ.

The results of the pre-post comparisons of this study showed significant increment of 5.23% in the VO_2 of EG (from 40.72 to 42.85 ml/kg/min) and insignificant increment in CG (4.73%; from 42.06 to 44.05 ml/kg/min). The result showed that BF running was 2.7% more economical as compared to shod running. This is similar to the findings of Hanson et al. (2011) where BF running was 3.8% more economical than running with shoes and the subjects with shoes had a 5.7% higher $\dot{V}O_2$Max. The superior RE is quantified as the submaximal oxygen uptake, has been associated with a lower $\dot{V}O2$max in distance runners (Fletcher et al., 2009; Morgan & Daniels, 1994). Similarly, in a meta-analysis of 13 studies which included 168 runners, Cheung and Ngai (2016) found that BF running was more economic than shod running.

The advantage of BF running was reported in a study by Wilkinson, et al. (2015) on the performance of 13 runners with shod and BF on separate days on treadmill (6-min treadmill runs at an average speed of 12.5 km/hour. Average oxygen cost decreased in BF as compared to shod running (90% CI -11% to -3%). Earlier research (Burkett et al., 1985; Catlin & Dressendorfer, 1979) reported that running BF could reduce oxygen cost at any given running speed. Similar findings were also revealed in numerous studies comparing RE in BF and shod running where 5 out of eight studies have reported significant reductions in the oxygen cost (Burkett et al., 1985; Catlin & Dressendorfer, 1979; Divert et al., 2008; Hanson et al., 2011; Perl et al., 2012). Conversely, Franz et al. (2012) in examining the Metabolic Cost of Running Barefoot versus Shod (lightweight cushioned,≈150g) involving 12 males with substantial BF running experience found insignificant difference in VO_2 in the two situations. In fact, shod running had 3-4% lower VO_2 than BF running. This insignificant result agrees with numerous earlier studies (Burkett et al., 1985; Frederick et al., 1984; Squadrone & Gallozzi, 2009). According to Cavanagh and Williams (1982), the higher VO_2 in BF runners was probably due to the fact that they preferred shorter and faster strides as compared to the greater stride length in shod runners. In another study to determine if the use of a systematic BF running training programme would result in an improved RE and race performance, Baroody (2013) reported that a progressive, 10-week BF running training programme improved RE and running performance.

A review by Jenkins and Cauthon (2011) in the Journal of the American Podiatric Medical Association concluded that scientific evidence had not yet provided conclusive evidence to support or refute the advantages of BF running over traditional shod running, however; the review noted that BF running may be an acceptable method of training.

Barefoot Running Training Programme and Ground Reaction Force

Although numerous studies have focused on comparing shod running and BF running and their effects on VO_2, the studies did not examine the effect of GRF. Thus, this study investigated the GRF of recreation runners. The results of this research revealed that there was greater reduction in the GRF for EG (barefoot runners) as compared to the CG (shod runners). The superiority in GRF for EG over CG was for both the left and right foot.

The results is supported by the findings of Lieberman et al. (2010). They performed kinematic and kinetic analyses on runners and found that barefoot runners strike the hard surface using forefoot as compared to shod runners which had plunged the ground using rearfoot. The forefoot strike generated smaller collision forces than rearfoot strike. The smaller force could be explained by a more plantarflexed foot at landing and more ankle compliance during impact thus decreasing the body effective mass of the body when contact was made with the ground.

In a systematic review of biomechanical differences between running BF and shod, Hall et al. (2013) reported moderate evidence that BF running was associated with reduced peak GRF, increased foot and ankle plantarflexion and increased knee flexion at ground contact compared with shod running. In addition, the review also revealed that BF running with forefoot strike pattern appeared to reduce loading rate while shod running with RF strike pattern had loading rate increased.

Another meta-analyses of kinematic variables on 16 studies by Almeida et al. (2015) reported significant differences between forefoot and rearfoot strikers for foot and knee angle at initial contact and knee flexion range of motion. A forefoot-strike pattern resulted in a plantar-flexed ankle position and a more flexed knee position, compared to a dorsiflexed ankle position and a more extended knee position for the rearfoot strikers, at initial contact with the ground. In fact, rearfoot strikers had higher vertical loading rates compared to forefoot strikers.

Hasegawa et al. (2007) examined the strike pattern and the association between Ground Reaction Time (GRT) and finishing in half-marathon and reported a significant relationship between GRT and finishing in the race, and better position was achieved with shorter GRT. In addition, they revealed that a quarter of the competitors who were forefoot (FFS) and midfoot strikers (MFS) (187.4 ms) had shorter GRT than rear foot strikers (RFS) (199.8 ms). Similarly, in a study of 181 middle distance runners, Hayes and Caplan (2012) found both forefoot and midfoot strikers had shorter average GRT than rear foot strikers.

Numerous researchers (Cavanagh & Lafortune, 1980; Lieberman et al., 2010) have confirmed that FFS is characterized by a reduced impact peak for the GRF and RFS is characterized with a huge impact peak and an increased loading rate of the vertical GRF (Milner et al., 2006). Similarly, Lieberman et al. (2010) and Williams et al. (2000) revealed that FFS was associated with decreased vertical loading rate. In addition, in investigating the running gait of habitually unshod runners, Lieberman et al. (2010) reported that FFS did not generate high impact peaks caused by RFS.

In examining the combined effects of foot strike pattern, step rate and anterior trunk lean gait modifications on impact loading in 19 healthy runners, Huang et al. (2019) found that FFS combined with increased step rate had a lower impact loading rates as compared to RFS combined with anterior trunk lean. However, in reviewing 18 studies to evaluate biomechanical differences between running BF and shod, Hall et al. (2013) reported moderate evidence that BF running was associated with reduced peak GRF. In fact, their review indicated that barefoot FFS reduced loading rate as compared to RFS. Further, in investigating

12 physically active participants (7 females, 5 males) to determine the differences in GRFs between BF and shod running, Meredith et al. (2015) found that there was no significant difference between the peak impact force between BF (1245.03 +/- 545.0 N) and shod running (1331.8 +/- 567.4 N; $p>0.05$).

Thompson et al. (2016) studied 10 physically active and healthy runners running in 3 conditions (BF and BF while heel striking, shod). They reported that both BF and shod runners showed decreased impact peak magnitude. In addition, they revealed that BF runners had decreased impact peak magnitude as compared to increased impact peak magnitude in shod runners.

In numerous other previous research (Cavanagh & Lafortune, 1980; Laughton et al., 2003; Lieberman et al., 2010; Nilsson & Thorstensson, 1989), it was suggested that FFS was better than RFS in reducing the potential of injury risk when running. The vertical component of GRF during the early stance phase, and the loading rate of that force, were smaller for FFS and MFS than for RFS. This is supported by Kulmala et al. (2013) who examined the difference in limb loading profile among 19 female athletes between RFS and FFS runners. FFS runners exhibited lower patellofemoral contact force and stress as compared to RFS runners.

The result of this study revealed that right foot (RL) reduced GRF larger (4.5%) as compared to the left foot (LF) (2.9%) in the EG. While CG reported greater reduction in GRF in the LL (1.68%) as compared to RL (0.54%). Over all, EG has greater reduction in GRF for both legs as compared to CG. The results are supported by Tam et al. (2016) where a similar BF running training programme for 8 weeks with 3 sessions per week was applied. Tam et al. (2016) reported GRF was reduced for both BF and shod running subjects. The loading rate changes ($p < 0.001$) for BF and shod runners was 12.9 kg/s and 9.8 kg/s respectively. However, it was not reported the differences between RF and LF. Similarly, other researchers (Divert et al., 2008; Squadrome & Gallozzi, 2009) also reported that there was decrement in GRF for barefoot strikers but which legs had higher percentage of reduction was not reported.

CONCLUSION

The present study has shown significant improvement in VO_2 of EG as compared to insignificant improvement in CG. Our results also revealed a greater reduction in the GRF for BF compared to shod runners, both in the right and left foot. BF running was 2.7% more economical as compared to shod running, suggesting a possible ergogenic benefit of barefoot compared to shod running. The improvement in VO_2 of EG appears to be related to the removed shoe mass in barefoot runners which helped in reducing the mean oxygen cost of steady-state running. BF running is associated with some alterations to gait which runners strategized to avoid impact (plantar-sensory feedback hypothesis) and this is associated with oxygen cost reduction. Further research is needed to examine foot strike pattern and speed of striking of BF runners.

ACKNOWLEDGEMENT

We would like to thank the Faculty of Applied Sciences, Tunku Abdul Rahman University College, Kuala Lumpur for providing the financial support, both for the conference fee and the publication fee.

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